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THIRD US ARMY WORKSHOP ON ENGINE LUBRICATION

SESSION REPORTS

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THIRD US ARMY WORKSHOP ON ENGINE LUBRICATION (?) ,

13/14 APRIL 1988

SESSION: Correlation Between Bench Tests with Field Service Tests

Report by: R Robson - Paramins

A "scene setting" presentation for this session highlighted problems of precision of bench engine tests and pointed out the need for more independent monitoring of the tests. These two items contributed to problems of correlation between bench and field tests. Correlation was necessary for engine and lubricant development purposes and often relied upon experienced personnel's interpretation of results. Examples of successful correlation were presented drawing on experience with the Ford Tornado, the Sequence 5E and a European sludge test. It was concluded that a moderate level of overall correlation existed and that this was supported by the fact that the automotive and lubricant industries had a good record of satisfactory field service. Precision and proliferation of bench engine tests were factors that had to be controlled if cost effective, market driven development work was to be carried out.

In the discussion that followed, precision, or perhaps more appropriate, discriminating power, of bench engine tests was cited several times as contributing to the problems of correlation. Examples of problems of repeatability with the Caterpillar 1G-2 and the Petter AV-B were given. Variability at the "overall" level (deposit rating for example) the micro level (eg lubricant film thickness) was quoted. The characteristics of an engine could change significantly during a single test and can be revealed by real time monitoring. The possibility of variation between batches of reference oils and ageing effects in a single batch of reference oil was pointed out and supported with Petter AV-B data. In one case tests carried out on the same batch of oil with a gap of one year between tests gave vastly different results. It was pointed out that field tests are also subject to variability and suggested that each field test should be regarded as an individual evaluation so that the question of which test one is trying to correlate with arises.

Several pleas for intelligent interpretation of data were made and the argument applied to rig, bench engine and field tests as well as to the correlation between them. Efforts to capture more data from these various tests were felt to be of great value. Parameters such as surface condition and frictional characteristics in rig tests and critical running temperatures in bench engine tests should be recorded. In particular the use of standard engine tests to determine, for example, liner temperatures would be valuable. More sophisticated analytical and measurement techniques should be applied to field tests, a wealth of extra data could be obtained and the extra cost involved would be minor. In addition it was pointed out that field testing would benefit from more careful selection of parts prior to commencement.

The multivariant nature of field testing was contrasted with the "one parameter at a time" approach intrinsic to bench, and more particularly rig testing. Perhaps it would be more sensible to try to correlate the outcome of a field test with some combination of bench engine results rather than with one particular evaluation. In spite of this difference some data on the correlation between a differential scanning calorimeter (DSC) study and results in terms of both deposit rating and oil consumption in a field test in Cummins engines was presented. On the basis of rather limited data it was also shown that measurements taken with the Cameron-Plint machine correlated with the performance of reference oils in field service. In this case plots of contact potential corresponding to asperity contact showed a relationship with field performance of oils from three different sources.

Running bench or field tests under very severe conditions and assuming that satisfactory results automatically covered the less severe case was said to be an unsound approach. This argument was supported by reference to the non-linear nature of the relationship between wear and reactivity and wear and surface hardness. In both cases the plots go through a minimum. In the case of hardness, low values could give rise to adhesion, high ones to brittle fracture. At low reactivity the inert surfaces do not respond to additives and at high reactivity corrosion could occur. It was pointed out that failure modes can frequently vary with variation in test conditions, accelerated bench testing utilising high severity conditions can therefore fail to accurately predict the outcome of a field test. The necessity of careful running in of any experiment measuring wear behaviour was emphasised.

Interaction effects between fuels and lubricants were said to be frequently ignored whereas significant contamination of lubricant by fuel does occur and can have a major impact upon performance. Interactions between oils and other materials were also mentioned and it was pointed out that used oils can differ considerably from fresh oils in this regard. A plea was made for the inclusion of used oils in rig test studies, this is a feature that is often ignored and for essentially all of an engine's life it is actually operating with a used lubricant. Difficulties in using representative samples of used oils arise largely because these materials are difficult to store, they invariably change with time with reactions continuing to occur at room temperature. It was pointed out that this can be largely overcome by storage of the samples in a freezer. Bulk oil temperatures in rig tests should be controlled and quoted as they can have an effect upon the result obtained due to the different "activation" temperatures of any additives used. ZDDPs are sensitive to this parameter and this can have a major effect upon the results obtained.

Computer modelling of the lubrication of an engine was proposed as the best means of providing the level of understanding necessary for assurance of satisfactory performance. Discussion on this topic was lively with concerns being expressed over the complexity of the process and the feasibility of ever achieving a satisfactory overall model. It was generally agreed

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however that modelling of the lubrication of critical components was both possible and desirable.

Concern over the availability of field test data was expressed, it was believed that much field testing was regarded as confidential with the results being proprietary to the automotive manufacturer or oil or additive company concerned. The question of the cost of field testing was raised. Costs vary widely with the nature of the test, use of hired drivers to achieve rapid mileage accumulation incurs heavy charges. Owner or employee driving saves costs at the expense of the time taken to complete the test. Field testing is inhibited not so much by cost per se however as by the time it takes to get a result. As a result field tests are frequently used to provide assurance of a product's acceptance in service rather than to provide useful technical data. It was pointed out that such tests are rarely run to failure whereas bench engines and, more frequently, rig tests, are.

In conclusion it is arguable that bench tests currently do a reasonable job of ensuring satisfactory field service although strict correlation between the two is rarely demonstrated. Reliance on empiricism in this area could be dangerous however and the low incidence of major field problems to date does not guarantee safety in the longer term. A sound understanding of the relationship between bench and field performance is needed to ensure future consumer satisfaction.

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THIRD US ARMY WORKSHOP ON ENGINE LUBRICATION

13/14 APRIL 1988

SESSION: The Effect of Additive Formulation on High Temperature Lubricants

Report by: D J Smith - Ricardo

Both evolutionary and revolutionary changes in engine design were considered to be major contributory factors in the need for high temperature lubricants. The pace of change was not believed to have abated since the first motor car over 100 years ago. The need for higher specific power outputs, lower exhaust emissions and greater fuel economy had led, in the recent past, to the appearance of 4 valve designs and a greater use of turbocharging in gasoline engines. On the diesel side legislative requirements for noise and emissions (especially particulate) are in the process of forcing major changes in design. Oil consumption reduction is high on the list of desirable features. Significant changes are being made to combustion chamber design and the use of turbocharged DI engines is moving apace.

Revolutionary change was being provided by the development, albeit at an early stage, of low heat rejection engines with the perceived features of high insulation levels, use of ceramics, high specific power outputs, and low oil consumption. A number of implications were seen as a result. The most notable design changes were believed to be the complete revision of cooling circuits with possibly a different balance between oil and water cooling and the raising of the top compression ring. New materials were thought to be an inherent part of the design with ceramics featuring heavily. Metal types would also need to be revised to keep in tune with the heat fluxes which would be different to those in current engines.

Discussion on the higher operating temperatures achieved by these engines raised a number of points. Although the lubricant may need to sustain higher temperatures the residence time at these temperatures would need to be considered in the development of adequate lubricant performance. It was observed that although temperatures in the vicinity of the top ring groove would increase dramatically other areas may see little or no change. It was felt that the ability to promote a rapid entry and exit to the hottest areas could be a critical factor. Some work had been carried out to investigate residence times in the top ring groove but it was generally agreed that this was insufficient to meet the needs of the development of lubricants for these engines.

While the ability to move the lubricant away quickly from the hottest parts of the engine would be advantageous in one respect it would have its own disadvantages resulting from the higher level of cyclic thermal stresses. Little information was available on this topic.

290°C was quoted as the bore temperature at top ring reversal in state-of-the-art low heat rejection engines but it was questioned whether this was the most critical temperature in the engine. It was proposed that the crown land temperature immediately above the top ring groove could be more important and other delegates felt that the valve train may prove to be the Achilles heel. Another proposal was that consideration should not only be given to the most vulnerable mechanical point but also that at which the highest level of oil degradation took place. The magnitude and type of oil degradation in conjuction with the relative percentage return rate of this oil to the sump were areas needing further investigation. This re-emphasised the belief that not only the temperature but also the residence time should be considered.

Moving on from the engine design features discussion centered around the lubricant needs to match them. Although residence time was not considered, temperature was considered in two stages. It was believed that in the short term lubricants would need to withstand temperatures in the region of 400°C and this was considered to be the feasible limit before external limitations imposed on the engine design metallurgy rendered conventional lubrication techniques invalid.

Looking at the performance criteria, four areas were highlighted. Antiwear capability was felt to be inhibited by the presence of ceramics. Current technology antiwear chemistries were attracted to the metallic surfaces to produce higher concentrations near rubbing surfaces. There was data available to indicate that this was not the case with ceramic materials and as a result of this there may need to be significant increases in the antiwear concentrations in the lubricant. While this was believed to be a supportable proposition some delegates indicated that certain ceramics had a greater affinity for antiwear attraction than others. There also appeared to be the belief that there was conflicting data available on the subject.

With the need for a tight control of oil consumption, the benefits afforded by the lower volatility of synthetic oils was noted.

It was noted that the detergent performance of lubricants needed to be maintained.

Brief mention was also made of the pressure co-efficient and it was noted that, while conventional petroleum basestocks showed an increase in viscosity with pressure, this was questionable for synthetics. This was considered to be a disadvantage for synthetics as this property would be needed for the highly stressed areas of the valve train which would operate at a relatively small increase in temperature.

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Discussion took place on the limitations of current and future lubricants at different top ring groove temperatures. At 200°C, limitations were considered to be viscosity, volatility and oxidative stability. At temperatures in the region of 300°C thermal stability and deposit control were called into question. Moving on to 400°C total loss systems were considered necessary and at 500°C it was thought that solid lubricants might be needed.

There was considerable discussion on synthetic basestocks as these were considered by many to be the natural short term solution to moderate increases in temperature.

A number of benefits were demonstrated by reference to test results. In particular the control of gasoline and diesel engine deposits were demonstrated by reference to multiple length sequence 3D tests and single cylinder engine tests, while improved control of turbocharger deposits from heat soak back were noted.

Perceived benefits of synthetics were considered to be a higher VI, lower volatility, better thermal stability and higher oxidative resistance. In addition it was considered that overall there was better property retention during the lubricants lifetime leading to longevity and durability.

Some considered that, as synthetics had been around in their present form for about 15 years, and had not made significant headway in that time, it was a reflection on their capabilities. Others felt that their earlier promise, demonstrated in the aircraft industry, had not been capitalised upon due to lack of need.

The benefits attributable to synthetics were believed to be due to their single molecular weight, which could be selected to be similar to the best values present in conventional basestocks. Various types of synthetics are available with a range of molecular weights and data was presented to show the 'pros' and 'cons' of each.

The corollary to the benefit of a single molecular weight was thought to be that if the synthetic was chosen incorrectly or operating conditions were not as expected there would be no buffer to provide support.

Alternatives to the use of synthetics were discussed. Single pass lubrication was thought to have merit as the durability of the lubricant was not a problem. In fact different criteria would be used to evaluate performance, as the lube's effect on the engine would be of sole importance and the resulting effect on the lubricant would be of little concern.

The use of single pass lubrication as a carrier was also a method to introduce solid lubricants into the engine. The liquid would decompose leaving the solid on the surface. Moly disulphide was thought to be the most widely developed but others were possible.

Reference to marine engine practice noted that, as oil consumption was of the order of 1% of fuel consumption, oil costs would be prohibitive. An additional disadvantage was the expected high level of particulates, and the add-on cost of cleaning up the exhaust.

Brief mention was made to solid lubrication of two types. PTFE was considered to have limited application above 350°C and moly disulphide was thought to have some small benefits. The problem with all forms of solid lubrication is the need to replace it due to wear and this has not yet been fully addressed.

Some work was described on gas lubrication, and it had been demonstrated as a feasible alternative. Very low friction levels and low emission levels, due to lack of any liquid lubricant near to the combustion chamber, were believed to be inherent benefits. At the present time only part of the engine - the piston rings - had been effectively lubricated in this way, with conventional lubrication used for bearings and valve train. Two problems areas were highlighted. Resonance of the ring pack due to the dynamics of the assembly were believed to be soluble as was the slow start to lubrication due to late lift-off.

The changes to additive packages were discussed. It was clear that major reformulations would be needed with a need for new molecules but delegates were not pessimistic about the task. It was believed that ash production would be the limiting factor in additive package development. It was noted that ZDDPs would become obsolete after moderate increases in temperature. However it was noted that alternatives were available now, although they were not yet in production.

The fuels on which high temperature engines would be running was discussed. Low sulphur fuel was expected to be the norm for commercial engines but it was expected that military units would need high sulphur fuel capability. There was a general belief however that engines operating at high temperatures would have an inherent multifuel capability.

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SESSION: Methodology for Making Measurements in Liquid Lubrication Systems

Report by: G M Hamilton - The University of Reading

Introduction

The general introduction to the session had been written in advance by Professor Dowson. When giving his verbal presentation he placed particular emphasis on three areas. He felt that early studies had given too much attention to the main bearings, to the almost complete exclusion of the piston rings and valve train assembly. Recent studies had shown that over half the friction losses came from these and that they deserved a proportional amount of effort. It was possible to both measure and calculate the oil film thicknesses in these components. It should thus be possible to model their working in future engine designs.

Secondly he said that he wished to emphasise the importance of parametric investigations and gave some examples. It was more important to know the way in which the friction or oil film thickness changed rather than trying to calculate the absolute values. Finally he put in a plea for more information to be got out of routine engine tests. He cited the example of piston ring profiles being taken before and after testing as an example of the type of thing he had in mind. (Jez)

Optical Measurements

Dr Philippa Cann gave a major presentation of the long series of studies being made on thin lubricant films at Imperial College. She explained the importance of making these measurements on the films while they were being actively formed in the contact. This was done by making one of the components transparent and viewing the optical interference fringes. Using a variety of techniques film thicknesses in the range 0.01 um to 0.4 um could be studied. She instanced the surprising result that for materials, like phosphate esters, the film formed was thicker in sliding than in rolling contact. The techniques could be extended to rough surfaces and contaminants. It was also possible to deduce the effective rheological properties of the lubricants.

A second phase of this work involved the use of an infra-red microscope. With this it was possible to measure the local temperature distribution as the lubricant passes through the contact. If the film thickness is kept very thin it is possible to avoid complications due to the emissivity of the lubricant itself - most of the signal coming from the metal surface. The transparent substance has to have a suitable window in the infra-red; sapphire was normally used. Starting from the temperature rise it was possible, using energy methods, to calculate the effective shear stress. It was rather pleasingly found that the values so obtained were in broad agreement with those deduced from disc machines: values in the range 10 MN/m^2 to 50 MN/m^2 were typical.

The presentation was made with a continuous stream of comments and questions from the audience. In particular it was agreed that the early problems with infra-red measuring techniques had been overcome. It should gradually be possible to introduce the technique as a routine feature of engine testing. It should even be possible to measure the temperature distributions at the top of a moving piston. Preliminary work had already been done at a number of establishments.

Direct Oil Sampling

There was a second major presentation of on-going work, this time by Dr Fox of Leicester Polytechnic. Here the measurements being made were less exotic and were already ebing applied to a working engine, a Petter AA1. Samples of oilwere being extracted from the region of the piston crown land and the back of the ring pack. This latter involved the use of a dynamic linkage with life times for the connection of up to 50 hours. Once the oil samples had been obtained it was possi;blet o subject them to all the traditional methods of lubricant analysis.

Depending on the position from which the sample was taken it was found that there were large increases in viscosity. This was attributed to both light fraction distillation and oxidation. As there was virtually no alteration in the sump oil it was concluded that there was very little interchange between these two 'reactors'. It was also found that the VI improver had lost most of its properties by the time it reached the piston crown. However it was pointed out by the audience that the polymer had completed its duties by then. Several other indexes of oil behaviour had also changed, in particular the Base No was down from an initial value of 7.5 to 1.35 at TDC.

The Workshop audience showed considerable interest in this item, much of the questioning having to do with the long term effects on an engine when it is idling. There was also a number of explanations offered for the author's observations about long term instabilities in the behaviour of the ring pack, cycle times of four to six hours being quite common.

Gamma Ray Tomography

Something completely different was then offered by Professor Walker who had been using methods, more normally associated with nuclear physics, to investigate the distribution of oil in an engine. Positrons were introduced into the oil by dissolving a solution of a suitable fluorine isotope. He explained that the imaging method depends on the simultaneous detection of the pair of gamma rays released when a positron is annihilated. These travel in precisely opposite directions and are intercepted by a pair of gamma ray detector banks placed either side of the engine. By detecting a sufficient number of these events it is possible to recreate three-dimensional image in the manner known as tomography.

A video was shown which explained the results obtained when the method was applied to a Rolls Royce Viper engine. Clearly the method is in its early stages and the audience had some difficulty understanding the details of the image formation. There was also some concern expressed about yet another method which involves the use of radioactive isotopes. However the speaker was able to reassure them on this point as the activity levels are very low and half-life is only two hours.

Oil Film Thickness

Dr David Hoult described his method of using a laser source to measure the oil film thickness in the region of the piston rings. This involved adding a fluorescent dye to the oil. The method was capable of levels of discrimination down to 0.1 um. Considerable care was needed with the calibration. It is of course again a method which requires the use of at least on optical port in the engine. Quite a lot of interest had already been expressed in this particular piece of work outside the formal sessions. Finally Mr Allison-Greiner presented some of his recent work on the formation of polymer layers beneath a reciprocating slider. He show, rather surprisingly, that it is possible to measure the film thickness of these very thin layers by capacitance techniques.

Closing Remarks

When summarising the overall effect created by the session it has to be accepted that it had not quite operated in the best traditions of the Workshop. Some very novel techniques were being described and inevitably the individual authors tended to dominate. However it was interesting to find that there were so many new techniques, involving fundamental physics and chemistry, being pursued in what is a fairly well established field. It was also clear that some of these methods would have very wide ranging implications in the investigation of the lubrication of engines.

By comparison there seemed to be less active work going on, aimed at solving some of the immediate problems, raised in the earlier sessions. Several members of the Workshop has expressed an interest in having routine temperature measurements available. This point had been emphasised by Professor Dowson in his introduction. It was generally felt that the available analytical skills were adequate for current engine design but that some of the thinking about engine requirements for 1995 would involve accepting designs with peak temperatures, on some parts of the lubricated surfaces, in the range 300°C to 400°C. These would undoubtedly present a real challenge to those responsible for developing appropriate measuring skills. The infra-red techniques looked particularly promising when viewed from this point of view.